Surname	Centre Number	Candidate Number
First name(s)		2

GCE A LEVEL

A420U20-1

Z22-A420U20-1

FRIDAY, 10 JUNE 2022 – AFTERNOON

PHYSICS – A level component 2

Electricity and the Universe

2 hours

For Examiner's use only		
Question	**Maximum Mark**	**Mark Awarded**
1.	**10**	
2.	**11**	
3.	**13**	
4.	**19**	
5.	**15**	
6.	**10**	
7.	**10**	
8.	**12**	
Total	**100**	

A420U201 01

ADDITIONAL MATERIALS

In addition to this examination paper, you will require a calculator and a **Data Booklet**.

INSTRUCTIONS TO CANDIDATES

Use black ink or black ball-point pen. Do not use gel pen or correction fluid.
You may use a pencil for graphs and diagrams only.
Write your name, centre number and candidate number in the spaces at the top of this page.
Answer **all** questions.
Write your answers in the spaces provided in this booklet. If you run out of space, use the additional page(s) at the back of the booklet, taking care to number the question(s) correctly.

INFORMATION FOR CANDIDATES

The number of marks is given in brackets at the end of each question or part-question.
The assessment of the quality of extended response (QER) will take place in question **2(a)**.

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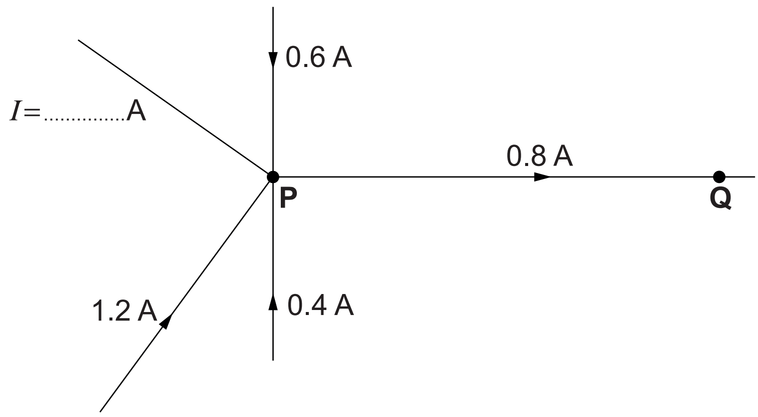
Answer **all** questions.

1. (a) Point **P** represents a junction in an electric circuit where five current-carrying conductors are joined.



(i) Determine the value of I and **indicate** its direction with an arrow **on the diagram**. [1]

(ii) Calculate the number of electrons passing point **Q** in one second. [1]

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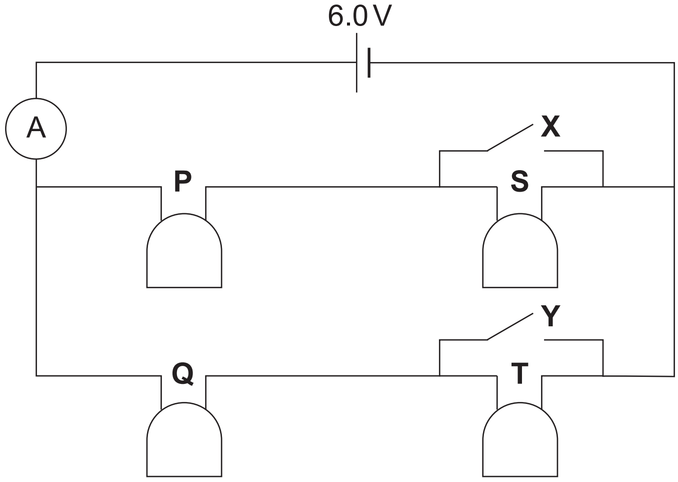
(b) Charlotte is investigating circuits involving combinations of buzzers. In the circuit below, buzzers **P**, **Q**, **S** and **T** can be controlled using switches **X** and **Y**. The buzzers are identical and their resistances remain constant.



Switches **X** and **Y** are shown **open**. In this arrangement all four buzzers are **ON**.

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(i) With **X** and **Y** open (as shown), the ammeter reads 18.2 mA. Calculate the resistance of **each** buzzer. [2]

(ii) Charlotte predicts that the ammeter reading increases when **X** is closed **and** increases further when **X** and **Y** are closed. Determine whether or not she is correct. [3]

(iii) Charlotte uses a decibel meter to measure the loudness of the sound emitted by the buzzers. She records that the sound emitted is twice as loud when only two buzzers are operating compared to when all 4 buzzers are operating. By determining the power, show that Charlotte's measurements are to be expected. [3]

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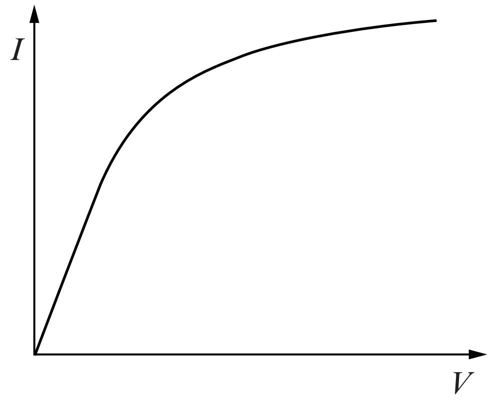
2. (a) The diagram shows the I-V characteristic for the filament of a lamp. Describe and explain in detail the shape of the graph referring to the motion of free electrons. [6 QER]



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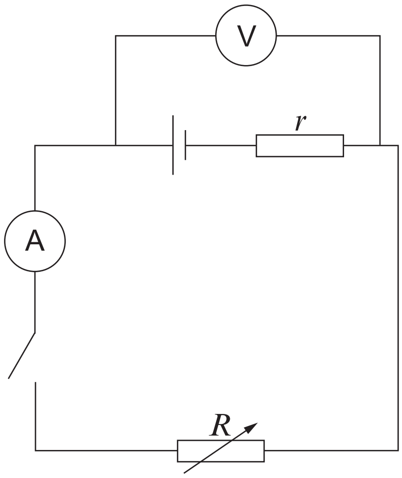
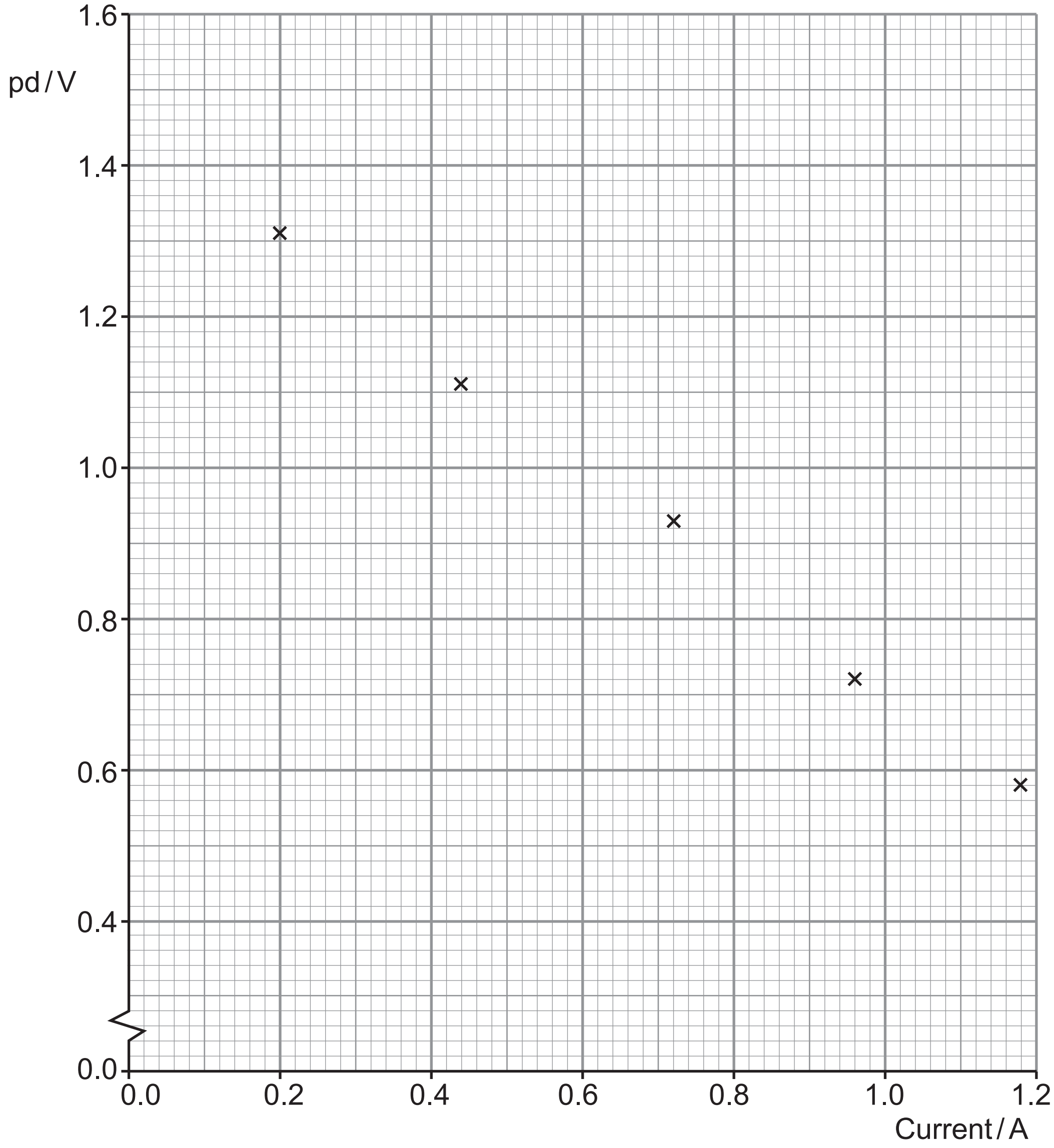
(b) Megan uses the following circuit to determine the emf and internal resistance, r, of a cell. By adjusting the variable resistor, R, a series of current and pd readings are taken and plotted as shown.





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(i) Determine the emf and the internal resistance of the cell. (Uncertainties are **not** required.) [4]

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(ii) As part of her experimental write-up, Megan makes the following statement:

Readings of V and I will be taken quickly with the switch closed. I will ensure the switch is open between readings.

State the importance of this technique when carrying out this experiment. [1]

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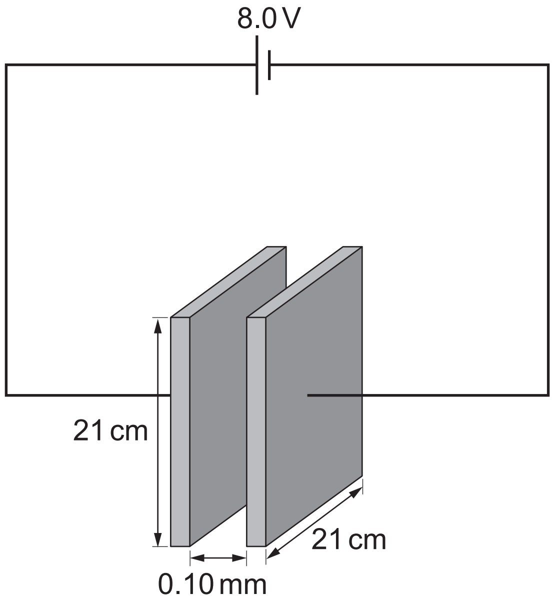
3. (a) A physics student wishes to construct a capacitor which will store 31 nC of charge when connected to an 8.0 V power supply. He carries out some calculations and determines that placing two **square** aluminium plates of side length 21 cm a distance of 0.10 mm from each other (as shown) would be suitable. The diagram is not to scale.



(i) Determine whether or not this capacitor set-up will store the required charge. [3]

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(ii) State how the student could increase the charge stored without changing any of the dimensions of the capacitor, or the power supply to it. [1]

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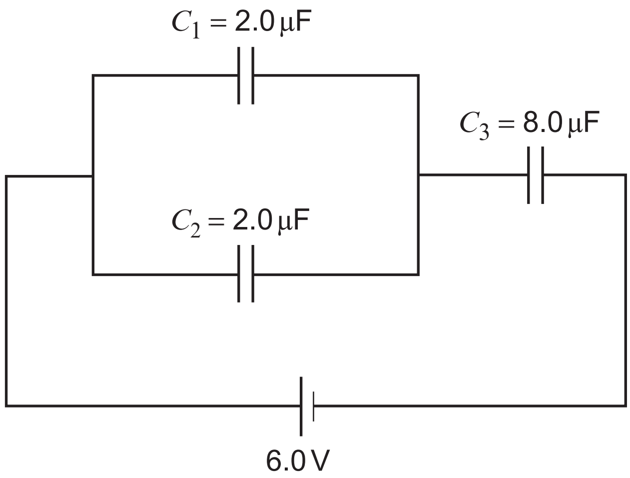
(b) The diagram shows a combination of capacitors, C_1, C_2 and C_3 connected to a 6.0 V power supply.



Determine the charges on each of the capacitors and the potential differences across them. [6]

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(c) Two identical capacitors, A and B, are charged to a pd V. Capacitor A is connected to a resistor of value R and capacitor B is connected to a resistor of value $\frac{R}{2}$.

The time taken for the charge on capacitor A to decrease from 16 nC to 8 nC is given by t.
The time taken for the charge on capacitor B to decrease from 16 nC to 2 nC is given by T.

Show that $T = \frac{3t}{2}$. [3]

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4. (a) In the production of steel alloy, atoms of carbon are added to iron. The resulting alloy is less ductile than pure iron. State the meaning of the term ductile, and describe, on an atomic scale, why the addition of carbon atoms can make steel less ductile than iron. [2]

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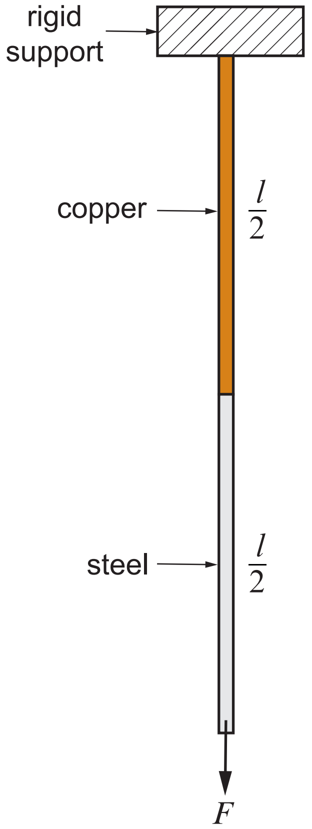
(b) Two wires, one of copper and one of steel, each of the same length $\frac{l}{2}$, and each with the same cross-sectional area, A, are attached end to end and suspended from a rigid support. A force, F, is applied as shown.



(i) The strain energy, W, in the wire combination due to the stretching force, F, can be given by $\frac{1}{2}F\Delta x$, where Δx represents the **total extension** in the wire combination. Show that: [3]

$$W = \frac{F^2 l}{4A}\left(\frac{1}{E_{\text{copper}}} + \frac{1}{E_{\text{steel}}}\right)$$

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(ii) Calculate W when $F = 45.0\,\text{N}$, given that $A = 0.6 \times 10^{-6}\,\text{m}^2$ and $l = 3.8\,\text{m}$, [$E_{\text{copper}} = 120\,\text{GPa}$ and $E_{\text{steel}} = 180\,\text{GPa}$]. [2]

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(iii) A student measures the total extension of the combination to be approximately 2 mm when $F = 45.0\,\text{N}$. Determine whether or not her measurement is consistent with your answer to (b)(ii). [2]

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(c) (i) Jasmine wishes to determine the Young modulus of a metal in the form of a wire. She makes the following measurements, along with uncertainties.

Diameter = 0.32 ± 0.01 mm
Initial length = 2.825 ± 0.005 m
Tension = 7.8 ± 0.1 N
Extension = 1.8 mm ± 0.2 mm

Determine the Young modulus of the metal, along with the **absolute** uncertainty in its value. Give your answer to an appropriate number of significant figures. [6]

(ii) Jasmine repeats her experiment by using a wire made of the same metal and original length, but with a **larger diameter**. Without further calculation, discuss how this change might affect the **uncertainty** in her result for the Young modulus. [4]

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5. (a) Define electric potential, V_E, at a point in an electric field. [1]

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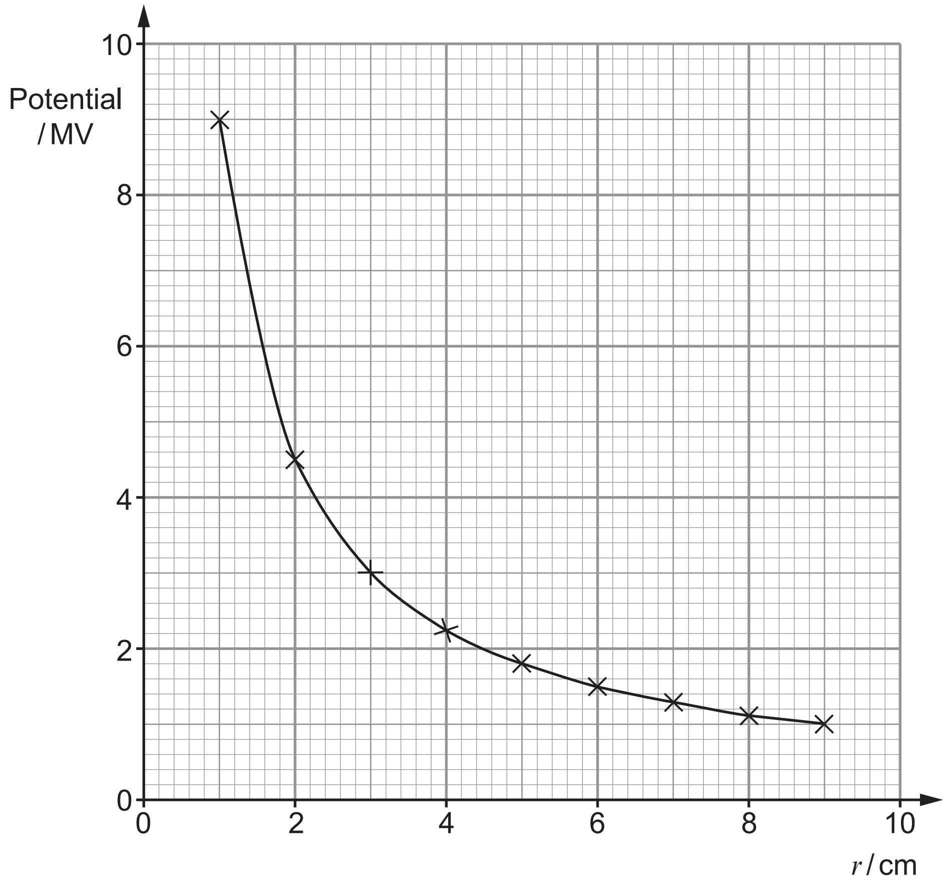
(b) The graph shows the variation of electric potential with distance, r, from an isolated positive point charge, Q.



(i) Use the graph to calculate the charge Q. [3]

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(ii) Calculate the work done to move a charge of +4.0 μC from 9.0 cm to 2.0 cm from the point charge. [2]

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(iii) The electric field strength at 3.0 cm from the charge is calculated to be $1.0 \times 10^{8}\,\mathrm{V\,m^{-1}}$. **Use the graph** to confirm this value. [2]

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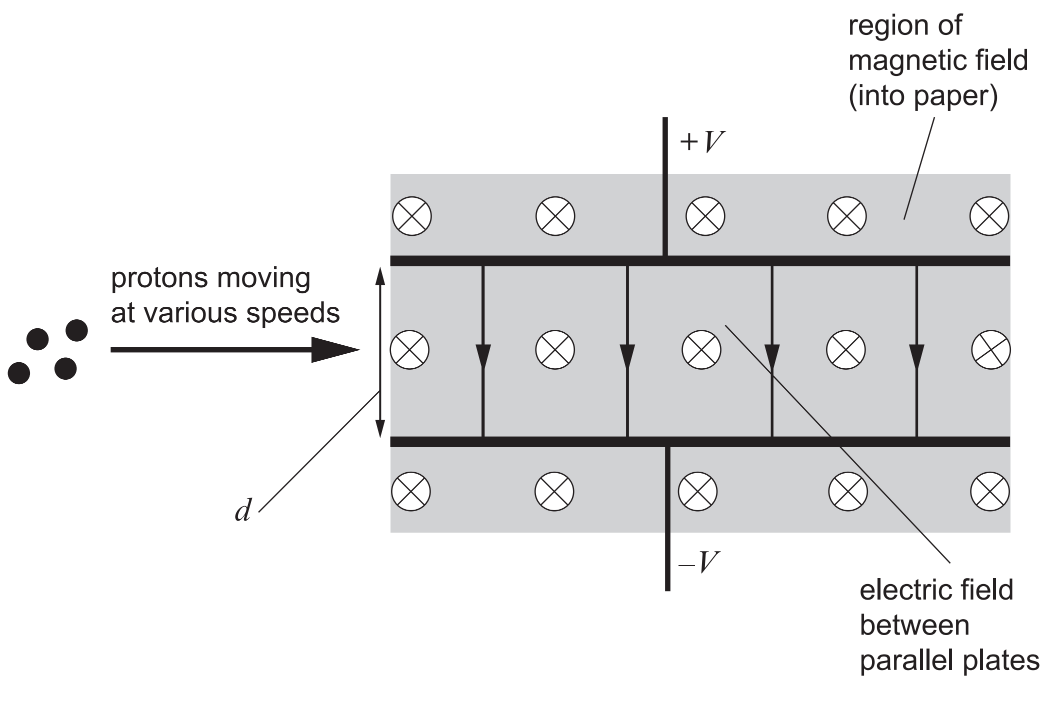
(c) The diagram shows the principle behind a velocity selector. An electric field is produced between two charged plates placed a distance, d, apart, having a potential difference, V, between them. The plates are placed within a magnetic field of flux density, B, which is directed into the paper, at right angles to the electric field. Protons, moving at various speeds, are directed into the combined fields as shown.



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(i) The magnitude and direction of the force due to the electric field on a proton is given by:

$$F_E = Eq \text{ directed downwards}$$

Write down an expression for the magnitude and direction of the force, F_B, due to the magnetic field on a proton. [1]

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(ii) Protons travel through the region of the combined fields in a straight line when $F_E = F_B$.
Show that, under these conditions, the speed, v, of the protons can be given by:

$$v = \frac{V}{Bd}$$ [2]

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(iii) With $B = 3.2\,\text{mT}$ and $d = 20\,\text{mm}$, determine the value of V, which would 'select' (allow) those protons with a speed of $6.0 \times 10^6\,\text{m s}^{-1}$ to travel through the fields undeflected. [2]

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(iv) Describe and explain the motion of a proton travelling at less than $6.0 \times 10^6\,\text{m s}^{-1}$ through these fields. [2]

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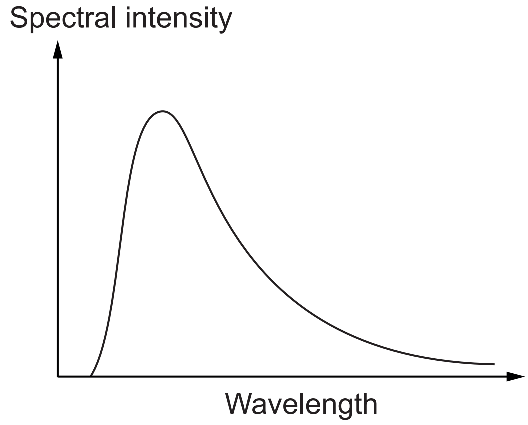
6. (a) The black body spectrum for a star is shown. Describe how it can be used to determine the temperature of the surface of the star. [2]



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(b) A website gives the following information about another star.

Radius of star / m	Black body temperature / K	Intensity of radiation from the star at Earth's surface / $W\,m^{-2}$
4.9×10^{10}	12 100	5.2×10^{-7}

(i) Use this information to calculate the distance of the star from the Earth. [4]

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(ii) The star is observed to be blue. Explain how the data supports this observation. [2]

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(c) In early 2020 the red supergiant star, Betelgeuse, underwent a period of rapid and unexpected dimming. Initially, one group of astronomers postulated that the dimming was due to the ejection of a large amount of gas from the surface, which in turn cooled to form a dust cloud, partially blocking the star's light as seen from the Earth (illustrated in Image A).

Later, a different group of astronomers suggested that the dimming was in fact due to temperature variations in the photosphere, the luminous surface of the star. High resolution images indicated huge star spots of lower temperature covering between 50% and 70% of the visible surface (illustrated in Image B). According to this study, their result isn't compatible with the presence of dust.

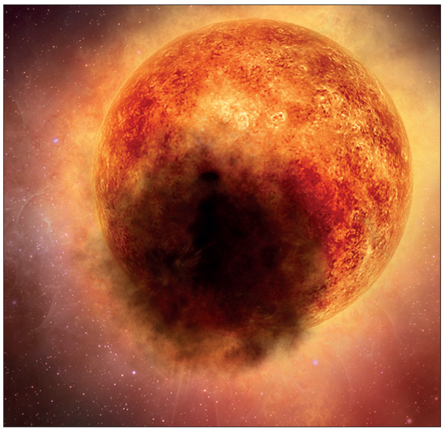

Image A

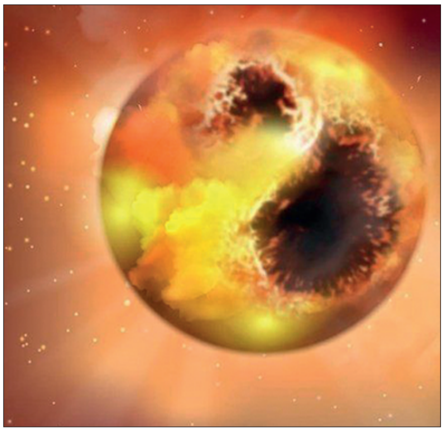

Image B

Suggest how the scientific community should proceed to evaluate these claims. [2]

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7. (a) (i) Stating an assumption, show that the age of the universe can be given by $\dfrac{1}{H_0}$ where H_0 is the Hubble constant. [2]

(ii) Quasars are extremely bright objects in the night sky. 3C48 is a quasar discovered in 1960 which is 4.60×10^9 light years from Earth and has a red shift, $\dfrac{\Delta\lambda}{\lambda} = 0.36$. **Use this information** to estimate the age of the universe. [4]

(1 light year $= 9.46 \times 10^{15}$ m.)

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(b) (i) Astronomers studying a spiral galaxy estimate from their observations that its mass is 4×10^{40} kg. Calculate the theoretical orbital speed of dust particles orbiting at a distance of 1.2×10^{21} m from the centre of the galaxy. [2]

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(ii) The measured velocity of the dust particles is found to be greater than the theoretical value calculated in (b)(i). Explain how astronomers account for this discrepancy. [2]

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TURN OVER FOR THE LAST QUESTION.

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8. (a) The gravitational field strength on the surface of the Moon is $1.62\,\text{N}\,\text{kg}^{-1}$, and its radius is $1.74 \times 10^{6}\,\text{m}$. Use this information to show that the mass of the Moon is approximately $7 \times 10^{22}\,\text{kg}$. [2]

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(b) An object's escape velocity is the speed at which it needs to travel away from a body such as a planet or moon for it to break free from the gravitational pull of that body.

(i) Use the principle of conservation of energy to derive an expression for the escape velocity, v, of a small body of mass, m, from a sphere of mass M and radius r. [2]

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(ii) Hence, calculate the escape velocity from the Moon. [2]

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(c) (i) The Moon's surface can reach a temperature as high as 400 K in direct sunlight. Show that the rms speed of oxygen molecules at this temperature is greater than $500\,\text{m}\,\text{s}^{-1}$. (The relative molecular mass of oxygen is 32.) [4]

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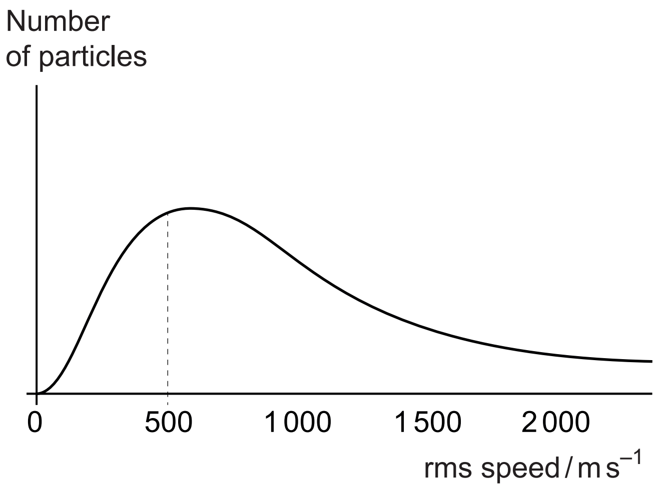
(ii) The sketch graph below shows the speed distribution of oxygen molecules at 400 K. Referring to the graph, suggest why the Moon does not have an atmosphere. [2]



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END OF PAPER

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Question number	Additional page, if required. Write the question number(s) in the left-hand margin.	Examiner only

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GCE A LEVEL

A420U20-1A

Z22-A420U20-1A

FRIDAY, 10 JUNE 2022 – AFTERNOON

PHYSICS – A level component 2
Data Booklet

A clean copy of this booklet should be issued to candidates for their use during each A level component 2 Physics examination.

Centres are asked to issue this booklet to candidates at the start of the course to enable them to become familiar with its contents and layout.

Values and Conversions

Avogadro constant	N_A	=	$6{\cdot}02 \times 10^{23}$ mol^{-1}
Fundamental electronic charge	e	=	$1{\cdot}60 \times 10^{-19}$ C
Mass of an electron	m_e	=	$9{\cdot}11 \times 10^{-31}$ kg
Molar gas constant	R	=	$8{\cdot}31$ J mol^{-1} K^{-1}
Acceleration due to gravity at sea level	g	=	$9{\cdot}81$ m s^{-2}
Gravitational field strength at sea level	g	=	$9{\cdot}81$ N kg^{-1}
Universal constant of gravitation	G	=	$6{\cdot}67 \times 10^{-11}$ N m^2 kg^{-2}
Planck constant	h	=	$6{\cdot}63 \times 10^{-34}$ J s
Boltzmann constant	k	=	$1{\cdot}38 \times 10^{-23}$ J K^{-1}
Speed of light in vacuo	c	=	$3{\cdot}00 \times 10^{8}$ m s^{-1}
Permittivity of free space	ε_0	=	$8{\cdot}85 \times 10^{-12}$ F m^{-1}
Permeability of free space	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
Stefan constant	σ	=	$5{\cdot}67 \times 10^{-8}$ W m^{-2} K^{-4}
Wien constant	W	=	$2{\cdot}90 \times 10^{-3}$ m K
Hubble constant	H_0	=	$2{\cdot}20 \times 10^{-18}$ s^{-1}

T/K = θ/°C + 273·15

1 parsec = $3{\cdot}09 \times 10^{16}$ m

1 u = $1{\cdot}66 \times 10^{-27}$ kg

1 eV = $1{\cdot}60 \times 10^{-19}$ J

$$\frac{1}{4\pi\varepsilon_0} \approx 9{\cdot}0 \times 10^{9}\ \mathrm{F^{-1}\,m}$$

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$\rho = \frac{m}{V}$	$T = 2\pi\sqrt{\frac{l}{g}}$
$v = u + at$	$pV = nRT$ and $pV = NkT$
$x = \frac{1}{2}(u + v)t$	$p = \frac{1}{3}\rho\overline{c^2} = \frac{1}{3}\frac{N}{V}m\overline{c^2}$
$x = ut + \frac{1}{2}at^2$	M / kg $= \frac{M_r}{1000}$
$v^2 = u^2 + 2ax$	$n = \frac{\text{total mass}}{\text{molar mass}}$
$\sum F = ma$	$k = \frac{R}{N_A}$
$p = mv$	$U = \frac{3}{2}nRT = \frac{3}{2}NkT$
$W = Fx\cos\theta$	$W = p\Delta V$
$\Delta E = mg\Delta h$	$\Delta U = Q - W$
$E = \frac{1}{2}kx^2$	$Q = mc\Delta\theta$
$E = \frac{1}{2}mv^2$	$I = \frac{\Delta Q}{\Delta t}$
$Fx = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$	$I = nAve$
$P = \frac{W}{t} = \frac{\Delta E}{t}$	$R = \frac{V}{I}$
efficiency = $\frac{\text{useful energy transfer}}{\text{total energy input}} \times 100\%$	$P = IV = I^2R = \frac{V^2}{R}$
$\omega = \frac{\theta}{t}$	$R = \frac{\rho l}{A}$
$v = \omega r$	$V = E - Ir$
$a = \omega^2 r$	$\frac{V}{V_{\text{total}}}\left[\text{or } \frac{V_{\text{OUT}}}{V_{\text{IN}}}\right] = \frac{R}{R_{\text{total}}}$
$a = \frac{v^2}{r}$	$C = \frac{Q}{V}$
$F = \frac{mv^2}{r}$	$C = \frac{\varepsilon_0 A}{d}$
$F = m\omega^2 r$	$E = \frac{V}{d}$
$a = -\omega^2 x$	$U = \frac{1}{2}QV$
$x = A\cos(\omega t + \varepsilon)$	$Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$
$T = \frac{2\pi}{\omega}$	$Q = Q_0 e^{-\frac{t}{RC}}$
$v = -A\omega\sin(\omega t + \varepsilon)$	$F = kx$
$T = 2\pi\sqrt{\frac{m}{k}}$	$\sigma = \frac{F}{A}$

$\varepsilon = \frac{\Delta l}{l}$	$n = \frac{c}{v}$
$E = \frac{\sigma}{\varepsilon}$	$n_1 v_1 = n_2 v_2$
$W = \frac{1}{2} Fx$	$n_1 \sin\theta_1 = n_2 \sin\theta_2$
$F = \frac{1}{4\pi\varepsilon_0} \frac{Q_1 Q_2}{r^2}$	$n_1 \sin\theta_C = n_2$
$F = G\frac{M_1 M_2}{r^2}$	$E_{\mathrm{k\,max}} = hf - \phi$
$E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$	$p = \frac{h}{\lambda}$
$g = \frac{GM}{r^2}$	$A = \lambda N$
$V_E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r}$	$N = N_0 e^{-\lambda t}$
$\mathrm{PE} = \frac{1}{4\pi\varepsilon_0} \frac{Q_1 Q_2}{r}$	$A = A_0 e^{-\lambda t}$
$V_g = -\frac{GM}{r}$	$N = \frac{N_0}{2^x}$
$\mathrm{PE} = -\frac{GM_1 M_2}{r}$	$A = \frac{A_0}{2^x}$
$W = q\Delta V_E$	$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$
$W = m\Delta V_g$	
$\lambda_{\mathrm{max}} = \frac{W}{T}$	
$P = A\sigma T^4$	
$\frac{\Delta\lambda}{\lambda} = \frac{v}{c}$	
$v = H_0 D$	

	leptons		quarks	
particle (symbol)	electron (e^-)	electron neutrino (ν_e)	up (u)	down (d)
charge (e)	– 1	0	$+\frac{2}{3}$	$-\frac{1}{3}$
lepton number	1	1	0	0

$\rho_c = \frac{3H_0^{\ 2}}{8\pi G}$	$E = mc^2$
$r_1 = \frac{M_2}{M_1 + M_2} d$	$F = BIl\sin\theta$
$T = 2\pi\sqrt{\frac{d^3}{G(M_1 + M_2)}}$	$F = Bqv\sin\theta$
$T = \frac{1}{f}$	$B = \frac{\mu_0 I}{2\pi a}$
$c = f\lambda$	$B = \mu_0 nI$
$\lambda = \frac{a\Delta y}{D}$	$\Phi = AB\cos\theta$
$d\sin\theta = n\lambda$	flux linkage = $N\Phi$

Mathematical Information

SI multipliers

Multiple	Prefix	Symbol
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c

Multiple	Prefix	Symbol
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E
10^{21}	zetta	Z

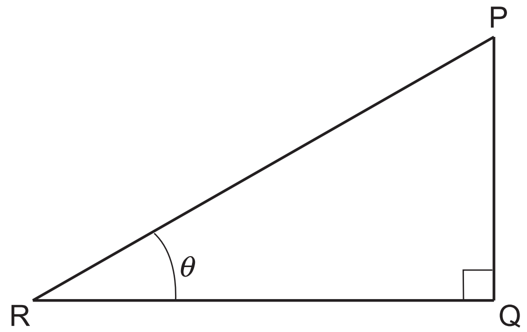
Areas and Volumes

Area of a circle = $\pi r^2 = \dfrac{\pi d^2}{4}$

Area of a triangle = $\frac{1}{2}$ base × height

Solid	**Surface area**	**Volume**
rectangular block	$2(lh + hb + lb)$	lbh
cylinder	$2\pi r(r + h)$	$\pi r^2 h$
sphere	$4\pi r^2$	$\frac{4}{3}\pi r^3$

Trigonometry



$$\sin\theta = \frac{PQ}{PR}, \quad \cos\theta = \frac{QR}{PR}, \quad \tan\theta = \frac{PQ}{QR}, \quad \frac{\sin\theta}{\cos\theta} = \tan\theta$$

$$PR^2 = PQ^2 + QR^2$$

Logarithms

[Unless otherwise specified 'log' can be $\log_e$ (i.e. ln) or $\log_{10}$.]

$\log(ab) = \log a + \log b$

$\log\left(\dfrac{a}{b}\right) = \log a - \log b$

$\log x^n = n \log x$

$\log_e e^{kx} = \ln e^{kx} = kx$

$\log_e 2 = \ln 2 = 0{\cdot}693$